

LIQUID ASPHALT MODIFIER

FIELD OF THE INVENTION

[0001] The present invention is directed to compositions and methods for providing an improved means of modifying asphalt with a polymer. More particularly, this invention provides a solvent system that permits addition of the polymer as a liquid that is preferred over solids addition and handling. The solvent system of this invention contributes to the final asphalt properties, as it is a reactive monomer that polymerizes *in situ*.

BACKGROUND OF THE INVENTION

[0002] The adhesive and waterproofing properties of asphalt have been known for centuries. Of the many applications of asphalt today, most asphalt derived from petroleum is used as paving material, commonly called asphalt cement. Asphalt (bitumen) is mixed with aggregate (rock) for use in paving.

[0003] Asphalt cement compositions must meet certain performance criteria or specifications to be considered useful for road paving. State and federal agencies issue specifications for various asphalt applications including specifications for use as road pavement. Performance standards are set forth in various standards of the American Society for Testing and Materials (ASTM) and the American Association of State Highway and Transportation Officials (AASHTO). Current Federal Highway Administration specifications designate an asphalt as meeting defined parameters relating to properties such as performance grading, viscosity, toughness, tenacity, and elastic recovery. Each of these parameters defines an important feature of an asphalt composition. Compositions failing to meet one or more of these parameters may be unacceptable for use as road pavement material.

[0004] More specifically, asphalt cement is viscoelastic in nature and its behavior is dependent on both temperature and loading. In hot conditions, asphalt cement acts as a viscous liquid and is subject to viscous flow. Under these conditions, less viscous hot mix asphalt

pavements flow under repeated wheel loading to form ruts. Such permanent deformation is called rutting. In cold climates or under rapidly applied loads, asphalt cement behaves like an elastic solid. If stressed beyond the material's capacity, such elastic solids may break. Some asphalt cements may become too brittle and crack when excessively loaded, resulting in low temperature cracking. Neither of these conditions is desirable in an asphalt cement.

[0005] Conventional asphalt compositions frequently cannot meet all of the requisite specifications, and damage to the resulting road can occur, such as permanent deformation, thermally induced cracking, and fatigue cracking. Conventional asphalts can be modified, however, with other substances to improve their performance properties. A wide variety of polymers have been used in this regard.

[0006] Polymer modified asphalt ("PMA") has become common in road paving and roofing and may represent as much as 20% of all asphalt used today. Improvements in rutting resistance, thermal cracking, fatigue damage, stripping, and temperature susceptibility have led polymer modified binder to be substituted for asphalt in many paving applications, including hot mix, cold mix, chip seals, hot and cold crack filling, patching, and slurry seal. PMAs are used wherever performance and durability are desired. Asphalt specifiers are finding that many of the Superpave binder grades need polymer modification to meet all the requirements for high temperature rutting resistance and thermal cracking resistance at low temperatures. Superpave, which stands for Superior Performing Asphalt Pavements, represents an improved, standardized system for specifying, testing, and designing asphalt materials.

[0007] Common polymers used for asphalt modification include styrene-butadiene block copolymers, styrene-isoprene block copolymers, ethylene-vinyl/acetate copolymers, polyethylene, and polypropylene. Typically, polymer addition involves addition of solid polymer, possibly after grinding, to a rear-shear mixing vessel containing asphalt generally heated above 325°F for a period of time to assure thorough mixing. This tends to be a labor and capital intensive process.

[0008] Despite the benefits of adding polymers to asphalt to improve physical and mechanical performance, polymers alone may not optimize asphalt performance. Also, the cost of adding polymer to the asphalt at levels sufficiently high to meet desired specifications may be prohibitive. As a result, the industry has developed chemical agents that enhance the performance of the polymer modifiers. Many of these agents have been termed crosslinkers and are widely used in the industry. They are believed to either crosslink the polymer to the asphaltene component of the asphalt or crosslink the polymer and improve properties. Improvements include superior performance in penetration, ductility, phase angle tests, as well as increased Strategic Highway Research Program (SHRP) grading. Use of chemical agents can result in more efficient utilization of the polymer, thus reducing the required level of polymer loading. There also may be improved compatibility between the polymer and the asphalt resulting in less separation of the polymer.

[0009] The earliest crosslinking systems involved use of sulfur. U.S. Patent No. 4,130,516 discloses an asphalt polymer composition obtained by hot-blending asphalt with 3% to 7% by weight of elemental sulfur and 0.5% to 1.5% by weight of a natural or synthetic rubber. U.S. Patent No. 3,803,066 discloses a process for preparing a rubber modified asphalt by blending the rubber in amounts up to 10% by weight, and blending into the mix an amount of sulfur such that the weight ratio of sulfur to rubber is between 0.3 and 0.9. A catalytic quantity of a free radical vulcanization accelerator is then added to effect vulcanization.

[0010] A more recent patent involving sulfur is U.S. Patent No. 6,180,697, which describes the use of a thermoplastic elastomer in concert with crosslinking formulations that include elemental sulfur, zinc-2-mercaptobenzothiazole, zinc oxide, and dithiodimorpholine. U.S. Patent No. 6,407,152 describes a crosslinker including two components. One component is a thiopolymer prepared by the reaction of butyl cresol and sulfur dichloride and the other component may be selected from the group consisting of elemental sulfur, polythiomorpholine, zinc-2-mercaptothiazole, and mixtures thereof.

[0011] U.S. Patent No. 6,057,390 describes a method for improved high temperature performance of asphalt comprising addition of a crosslinkable polymer (i.e., SBS triblock copolymer) and addition of dioxime of 1,4-benzoquinone or derivatives and optionally free radical initiators (i.e., organic peroxides). Another crosslinker for rubber modified asphalt compositions is provided by U.S. Patent No. 6,486,236. The rubber includes at least a polydiene and may include vinyl-substituted aromatic monomer units. The rubber is cured by a bismaleimide to improve softening points of the asphalt. The use of solvents for addition of the rubber and crosslinking components is not disclosed.

[0012] Asphalt has also been modified by the addition of polymerizable monomers to impact physical properties of the asphalt. A process is taught by U.S. Patent No. 3,547,850 for producing polymer-asphalt compositions that have a high softening point and improved penetration ratio, by effecting a polymerization in hot asphalt. This patent claims addition of an alkali metal (as a catalyst or initiator) and a monomer selected from the group consisting of conjugated dienes containing 4-12 carbons and vinyl substituted aromatic compounds, in heated asphalt to effect the polymerization of used monomers therein.

[0013] Another modified system has been described in U.S. Patent No. 4,273,685 to aid the compounding of asphalt systems with fillers such as glass fibers. This describes asphalt that has been reacted with a polymerizable vinyl monomer and a rubbery polymer added separately. The reaction is carried out at a temperature at which the vinyl aromatic monomer and the rubbery polymer react with the asphalt. Improved bonding of chemical modified asphalts with reinforcing fillers was also noted in U.S. Patent No. 4,332,705, which claims asphalt reacted with a polymerizable monofunctional vinyl aromatic monomer such as styrene, a polyfunctional polymerizable vinyl aromatic monomer such as divinylbenzene, and a rubbery polymer added separately.

[0014] Yet another factor for consideration in asphalt compositions is the use of solvents. Solvents have been used to fluidize asphalt polymer compositions, such as with small amounts of sulfur, as in U.S. Patent No. 4,242,246. Such solvents also may be used to fluidize polymers. The use of large amounts of solvents, however, may lower the viscosity of the resulting asphalt compositions such that they become too soft for road paving applications. In contrast, the incorporation of solid rubbers directly into asphalt presents process and handling difficulties and the uniformity of the final composition is often difficult to achieve or control. Separation of the solid polymer from the asphalt is also problematic. It is therefore desirable to develop compositions and methods for adding polymers to asphalt in a reactive monomer solvent in order to improve processing, achieve and sustain compositional uniformity, while improving or at least not compromising requisite asphalt properties.

SUMMARY OF THE INVENTION

[0015] The present invention describes a solution of a polymer for modifying asphalt dissolved in a polymerizable monomer, which represents a pumpable fluid that can be used to feed to an asphalt producing system. In accordance with the present invention, the asphalt compositions include asphalt and a solution containing a polymerizable monomer solvent and a rubber or elastomeric polymer. The compositions may further include additional components, such as crosslinking agents, free radical initiators, and inhibitors.

[0016] The present invention also describes a method for addition of a polymer to asphalt that involves dissolving the polymer in a polymerizable monomer and feeding it to the asphalt as a liquid. The solvent will "disappear" in the asphalt matrix and the resulting polymer will contribute to the final asphalt properties. Addition of the polymer/monomer solvent component to asphalt is desirably performed using heated asphalt, thus initiating polymerization. As such, the methods of the present invention include the steps of heating the asphalt, dissolving the rubber or elastomeric polymer in a polymerizable monomer solvent to form a polymer solution, and adding the polymer solution to the heated asphalt.

DETAILED DESCRIPTION OF THE INVENTION

[0017] In accordance with the present invention, it has been discovered that a polymer composition, which is normally a solid by nature, can be added to heated asphalt by dissolving it in a polymerizable monomer to facilitate addition as a liquid. The monomer polymerizes under the addition conditions and overcomes problems associated with use of solvents in asphalt. This method also overcomes the significant solids handling issues associated today with the addition of polymer solids. As such, embodiments of the present invention desirably include a pre-formulated solution of a polymer for modifying asphalt dissolved in a polymerizable monomer, which represents a pumpable fluid that can be used to feed to an asphalt system.

[0018] The polymer used in the compositions of the present invention may be any of rubber or elastomeric polymers typically used to modify the properties of asphalt. Conventionally utilized rubber or elastomeric polymers include block copolymers, thermoplastics, thermosetting resins, synthetic and natural rubbers, and fibers, among others. Examples of suitable polymers include styrene-butadiene copolymer, styrene-isoprene copolymers, ethylene/vinyl acetate copolymers, polydiene, polyethylene, and polypropylene. Diene contributed monomer units may include 1,3-butadiene, isoprene, 2,3-dimethyl-1,3-butadiene, and 1,3-pentadiene. Suitable rubber or elastomeric polymers desirably are present in amounts of about 12% or less by weight of the asphalt composition.

[0019] It is desirable to employ styrene-butadiene block copolymers, particularly styrene-butadiene-styrene block copolymer ("SBS"), due to their widespread acceptance in the asphalt industry. Specific styrene-butadiene polymer examples include Stereon (available from Firestone), Finaprene (available from Atofina), and Kraton (available from Kraton) product lines. Molecular weights of the polymers desirably may range from about 20,000 to 500,000.

[0020] Additional monomer units may include vinyl-substituted aromatic hydrocarbons. Such monomer units may include styrene, α -methylstyrene, 1-vinylnaphthalene, 2-vinylnaphthalene, 1- α -methyl vinylnaphthalene, 2 α -methyl vinylnaphthalene, as well as alkyl

cycloalkyl, aryl, alkaryl, and aralkyl derivatives thereof, and di- or tri-vinyl-substituted aromatic hydrocarbons.

[0021] The polymerizable monomer used as a solvent in the compositions of the present invention may be styrene. Styrene is desirable because it is inexpensive and readily polymerizable. Furthermore, styrene is highly compatible with SBS polymers typically used to modify asphalt. Other easily handled monomeric materials, such as N-vinylpyridine, N-vinyl-2-pyrrolidone, α -methylstyrene, vinylnaphthalene, or alkylated styrene or mixtures thereof also may be employed.

[0022] In some embodiments of the present invention, additional components may be added to the asphalt compositions. Additional polymerizable materials, either in liquid form or dissolvable in the monomer, may be added alone or in combination with the monomers. Such materials may improve the physical properties of the polymer solution or provide superior properties to the resulting asphalt. For example, crosslinking agents, such as divinylbenzene, can be added with the polymer/monomer mixture.

[0023] More particularly, the polymer solution may contain asphalt additives that are used to crosslink the polymer in and/or with the asphalt. Crosslinking reagents typically result in improved high temperature viscosities, better compatibility of the polymer with the asphalt, and reduced polymer loading. For example, crosslinking agents may include sulfur donors as described in U.S. Patent No. 6,047,152, or bismaleimides as described in U.S. Patent No. 6,486,236, each of which is incorporated herein by reference.

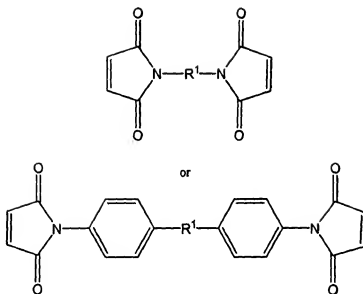
[0024] Polymer modified compositions of the present invention desirably include a combination of difunctional crosslinking materials, and optionally other additives such as initiators. These materials or components are added either directly to the asphalt (either neat or in a premix solution), or are included in the polymer/monomer solution, resulting in superior properties of the asphalt. Such asphalt compositions may exhibit improved dynamic shear

reometer values, such that the asphalt is more viscous at higher temperatures. The asphalt compositions also may exhibit a higher softening point, higher toughness and tenacity values, and better elastic recovery, among other benefits.

[0025] One such crosslinking component that may be added to asphalt is a difunctional monomer capable of polymerizing, generally by radical initiation, to form crosslinked polymer systems. Examples include, but are not limited to, divinylbenzene, diallylphthalate, diallylmaleate, ethoxylated bisphenol A dimethacrylate, polyethylene glycol dimethacrylate, and polyethylene glycol diacrylate. Useful ranges of crosslinking components may range from 0.1% to 3% by weight of the asphalt composition, more desirably 0.5% to 1% by weight.

[0026] A second crosslinking component may be added alone or in combination with the first crosslinking component. The second component may be a difunctional compound capable of reacting twice with appropriate functional groups, such as compounds that can react with olefins via reactions called ene reactions. Such compounds can thus couple two unsaturations, which may be available in a polymer, such as, for example, a polybutadiene, or in the asphaltene structures of the asphalt. A particularly desirable example of such compounds is the class of compounds called bismaleimides.

[0027] Suitable bismaleimides for use in the compositions of the present invention are represented, without limitation, by the following formulas:



wherein R^1 may be an aromatic group, an aliphatic group, a cycloaliphatic group, or an aliphatic group containing siloxane. Any bismaleimide, however, known to those of skill in the art may be used.

[0028] Specific examples of suitable bismaleimides include, but are not limited to, N,N' -m-phenylene-bis-maleimide, N,N' -hexamethylene-bis-maleimide, and N,N' -4,4''-diphenylmethane-bis-maleimide, N,N' -ethylene-bis-maleimide, N,N' -butylene-bis-maleimide, N,N' -phenylene-bis-maleimide, N,N' -4, 4'-diphenyl ether-bis-maleimide; N,N' -4,4'diphenyl sulfone-bis-maleimide, N,N' -4,4'-dicyclohexyl methane-bis-maleimide, N,N' -xylylene-bis-maleimide, N,N' -diphenyl cyclohexane-bis-maleimide, N,N' -(p-phenylene)-bismaleimide, N,N' -(p-tolylene)bismaleimide, N,N' -(methylenedi-p-phenylene)-bismaleimide, N,N' -(oxydi-p-phenylene)bismaleimide, α,α -bis-(4-phenylene)-bismaleimide, N,N' -(m-xylylene)bis-citraconimide, α,α -bis-(4-maleimidophenyl)-meta-diisopropylbenzene, and mixtures thereof. Useful ranges of bismaleimides include from 0.05% to 3% by weight of the asphalt composition, more desirably 0.1% to 2% by weight, and even more desirably 0.2% to 0.8% by weight.

[0029] Each difunctional crosslinking component or combination of components may be added to the asphalt independently, directly to or in a separate solvent solution or carrier, or may

be added as part of the polymer/monomer solution. For example, bismaleimide crosslinkers first may be dissolved in a solvent, such as, but not limited to vinyl pyrrolidone, prior to addition to the asphalt.

[0030] The asphalt compositions of the present invention may further include a free radical initiator. It may be advantageous to treat the asphalt composition with a free radical initiator, for example, to assist in the complete reaction of the polymerizable monomer and/or crosslinkers. Suitable initiators include, but are not limited to, molecular classes of peroxides, hydroperoxides, and azo compounds. Specific examples are di-tert-butylperoxide and cumenyl hydroperoxide. Initiator materials may be chosen based on the treatment temperature of the asphalt and/or the decomposition temperature of the initiator, thus to release the free radicals over the heated hold period. The initiator may be added independently or as part of the polymer/monomer solution at the reaction temperature or, alternatively, after some period of time up to 24 hours later. Useful ranges of initiators may include from 0.1% to 2% by weight of the asphalt composition, more desirably about 0.4% by weight.

[0031] Other additives, such as inhibitors, also may be added to the asphalt compositions of the present invention. Suitable inhibitors include, but are not limited to, t-butylcatechol, hydroquinone, hydroxyl-TEMPO, quinonemethides, diethylhydroxylamine, and combinations thereof.

[0032] The present invention also relates to methods of preparing asphalt compositions. In accordance with such methods, the rubber or elastomeric polymer may be added to the asphalt by first dissolving the polymer in a polymerizable monomer and, subsequently, feeding the solution to the asphalt as a liquid. The reactive solvent will "disappear", i.e. be integrated within, in the asphalt matrix and the resulting polymer will contribute to final asphalt properties. Addition desirably is performed to asphalt that is heated, thus initiating polymerization. Temperatures desirably range from about 200°F to 600°F, or more preferably from about 325°F

to 400°F. Completion of the polymerization is dependent on the temperature, i.e., longer cure time is needed for lower temperatures.

[0033] The polymer solutions prepared in accordance with the present invention may be added to asphalt at various times or locations. For example, it may be desirable to add the polymer solution in asphalt rundown lines at the refinery or heated storage tanks. Addition to process rundown conditions provides good agitation for thorough mixing of the polymer with the asphalt. This is a further advantage over addition of solid polymer, which is problematic due to reliance on high shear mixers for thorough mixing.

[0034] Furthermore, the addition of SBS polymer alone to asphalts can be problematic because the polymer tends to separate upon continued heating. Polymerizing reactive monomers such as styrene into the asphalt matrix, as in the present invention, provides improved stability of the polymer asphalt solution with reduced separation.

[0035] The polymer solution described herein may also contain small amounts of oils used to enhance asphalt properties. Such aromatic oils may result from furfural extraction processes and are known by those of skill in the art to improve the low temperature properties of asphalt. One example is Hydrolene Oils, available from Sunoco, Inc.

EXAMPLES

Example 1:

[0036] To 14.4 g of styrene inhibited with t-butylcatechol was added 9.6 g of a styrene-butadiene diblock copolymer Stereon 210 (available from Firestone Polymers). The mixture was gently heated to 150°F for 60 minutes to completely dissolve the polymer solids. The resulting solution had a viscosity at 70°F of 53,600 MPa. This solution was easily added to and blended with 400 g of asphalt. No polymer separation was apparent upon standing.

Example 2:

[0037] To a mixture of 11.5 g of styrene inhibited with t-butylcatechol and 2.9 g of divinylbenzene was added 9.6 g of styrene-butadiene copolymer Stereon 841A (available from Firestone Polymers). The mixture was gently heated to 150°F for 60 minutes to completely dissolve the polymer. The resulting solution had a viscosity (70°F) of 17,700 MPa. This solution was easily added to and blended with 400 g of asphalt. No polymer separation was apparent upon standing.

Example 3:

[0038] In an exemplary example, 400 g of Performance Graded ("PG") 64-22 asphalt (available from a Midwest U.S. refinery) was heated to approximately 350°F. Added to the asphalt were solutions of styrene butadiene (SB) copolymer Stereon 841A (available from Firestone Polymers) in polymerizable monomer, as described for samples A-G in Table 1 below. The polymerizable monomer used in these samples was styrene.

[0039] Further addition of tert-butylperoxide ("TBP") initiator, as well as crosslinker Vanax MBM (N,N'-m-phenylene bismaleimide) were performed in the amounts shown in Table 1. The resulting mixtures were blended with a blender at 7,000 rpm for 5 minutes. The solutions were subsequently heated for 3 days at 400°F.

[0040] The solutions were tested for various asphalt properties, including softening point, toughness, tenacity, true PG grade, and separation tests. Softening point was measured in accordance with ASTM D36-95, which is incorporated herein by reference in its entirety. Softening point is indicative of the tendency of the asphalt material to flow at elevated temperatures. Desirably, the softening point of the asphalt compositions of the present invention is between about 45°C and 95°C.

[0041] Toughness and tenacity were measured according to ASTM D 5801, which is incorporated herein by reference in its entirety. Tensile testing methods are described in U.

Isacson et al., "Testing and appraisal of polymer modified road bitumens - state of the art," 28 *Materials and Structures* 139,154 (1995) and L.H. Lewandowski, "Polymer Modification of Paving Asphalt Binders," 67 *Rubber Chemistry and Technology* 447, 456 (1994), each of which is incorporated herein by reference in its entirety. According to these methods, a hemispherical tension head is imbedded in hot molten asphalt, allowed to cool, and pulled at a specified rate to produce a load-deformation (stress-strain) curve. The entire area under the curve represents the toughness of the asphalt sample, while the area under the long-pull portion represents the tenacity.

[0042] True performance grade is understood by those skilled in the art to mean the temperature in °C at which the asphalt composition passes a performance test defined by dynamic shear rheometry ("DSR"). Passing high temperature grade for original asphalt is 1.0 kPa, and for RTFOT (rolling thin film oven test) asphalt is 2.2 kPa. If the asphalt fails at either of these conditions it is a non-pass. The true grade is defined by interpolation of DSR data run at discreet temperature increments as defined by the Superpave system.

[0043] Separation testing generally involves filling a tube, such as an aluminum tube, with the asphalt composition and storing it for a period of time at high temperature (e.g., 5 days at 160°C). After cooling, the tube material is peeled off and the specimen is cut into three equal parts. The top and bottom separation points then are measured. The separation test methods are described in C. Giavarini, "Polymer-Modified Bitumen," 40 *Developments in Petroleum Science* 381, 394 (1994), which is incorporated herein by reference in its entirety.

[0044] The results of the asphalt testing for samples A-G, provided in Table 1, indicate acceptable polymer performance when treated with monomer solutions. Untreated asphalt is displayed by sample A. Sample G was treated with the styrene dissolved polymer (3%) in combination with crosslinkers and it provided significantly improved softening point, toughness, tenacity and performance grade. Performance was even superior to sample B, which was 4% polymer treated as a solid by traditional addition methods.

TABLE 1

Component	A	B	C	D	E	F	G
Asphalt (g)	400	400	400	800	400	400	400
Styrene (g)			26.7	42.6	21.3	21.3	21.3
Polymer (g)		16	12	24	12	12	12
Divinylbenzene (g)				8.5	4.2	4.2	4.2
Crosslinker ¹ (g)				6.4		3.2	2.0
Initiator ² (g)			2.0	1.6	2.0		2.0
Softening Point (°F)	121	129	116	125	120	126	130
Toughness (in-lbs)	68	152	66	80	59	96	186
Tenacity (in-lbs)	19	77	20	47	30	53	122
True Performance Grade (°C)	67	71	64	70	67	69	73
Separation (top/bottom) (°F)				128/128			

¹ Vanax MBM (available from R.T. Vanderbilt Co., Inc.)² Tert-butylperoxide**Example 4:**

[0045] In an exemplary example, 400 g of PG 64-22 asphalt (available from a Northeast U.S. refinery) was heated to approximately 350°F. Added to the asphalt were solutions of polymer Stereon 841A (available from Firestone Polymers) in polymerizable monomer, as described for samples H-K in Table 2 below. Further addition of initiator TBP as well as crosslinker Vanax MBM (N,N'-m-phenylene bismaleimide) were performed as described by the Table. The resulting mixtures were blended with a blender at 7,000 rpm for 5 minutes. The solutions were subsequently heated for 3 days at 375°F.

[0046] The solutions were tested for various asphalt properties, including softening point, toughness, tenacity, true PG grade, and separation tests, as described above. The results of the asphalt testing for samples H-K, provided in Table 2, indicate acceptable polymer performances when treated with monomer solutions. Significantly elevated softening points, toughness, tenacity and performance grades were found for samples H-J, versus untreated asphalt (sample K).

TABLE 2

Component	H	I	J	K
Asphalt (g)	400	400	800	400
Styrene (g)	12	12	23.4	
Polymer (g)	11.7	11.7	24	
Divinylbenzene (g)	2.3	2.3	4.7	
Crosslinker ¹ (g)	1.6	1.6	3.2	
Initiator ² (g)	1.4	1.4	2.8	
Softening point (°F)	139	135	140	125
Toughness (in-lbs)	132	116	135	50
Tenacity (in-lbs)	69	72	71	13
True Performance Grade (°C)	76	76	78	66
Separation (top/bottom) (°F)			144/143	

¹ Vanax MBM (available from R.T. Vanderbilt Co., Inc.)

² Tert-butylperoxide

Example 5:

[0047] In an exemplary example, 300 g of AC-10 asphalt was heated to approximately 400°F. Added to the asphalt were solutions of polymer Stereon 210 (available from Firestone Polymers) in polymerizable monomer, as described for samples L-Q in Table 3 below. Further addition of TBP initiator as well as crosslinker Vanax MBM (N,N'-m-phenylene bismaleimide) were performed as shown in Table 3. The resulting mixtures were blended with a blender at 7,000 rpm for 5 minutes. The solutions were subsequently heated for 3 days at 210°F.

[0048] The solutions were tested for various asphalt properties, including softening point, toughness, tenacity, true PG grade, and separation tests, as described above. The results of the asphalt testing for samples L-Q, provided in Table 3, indicate acceptable polymer performance when treated with monomer solution, as indicated by enhanced softening points, toughness and tenacity.

TABLE 3

Component	L	M	N	O	P	Q
Asphalt (g)	300	300	300	300	300	300
Styrene (g)			8.8	10.3	10.3	14.7
N-vinyl pyridine (g)			5.9	4.4		
Polymer (g)	16		12	12	12	12
Divinylbenzene (g)					4.4	
Crosslinker ¹ (g)			2.4	2.4	1.9	2.4
Initiator ² (g)			1.2	1.2	1.2	1.2
Softening point (°F)	137	113	184	132	120	126
Toughness (in-lbs)	47	20	57	113	60	60
Tenacity (in-lbs)	7	9	10	74	52	48
Separation (top/bottom) (°F)	139/137		156/169	162/156	157/155	155/154

¹ Vanax MBM (available from R.T. Vanderbilt Co., Inc.)

² Tert-butylperoxide

[0049] While there have been described what are presently believed to be the certain desirable embodiments of the invention, those skilled in the art will realize that changes and modifications may be made thereto without departing from the spirit of the invention, and it is intended to include all such changes and modifications as fall within the true scope of the invention.